Monitoring Trends of the VELO Detector Across LHC Runs

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Abstract

This report details the work on trend monitoring key aspects of the performance of LHCb VErtex LOcator (VELO) detector. Utilizing monitoring savesets from LHCb, the primary goal of this study is to create trend plots across different runs to inform the performance of the detector over time and ensure the quality and stability of the data being recorded. The quantities studied here include pseudo hit efficiency and occupancy. These trends are organized into multi-page plots, enabling more granular results. For occupancy, this work focuses on identifying and characterizing the most populated 2D regions (hotspots) within individual sensor cluster maps, and subsequently calculating the average occupancy within these precisely defined regions. Data is sourced from `VeloMon` and `VeloMonTrack` monitoring savesets then processed using Python scripts within the `piquet tools` framework to plot these quantities as a function of the LHC run number. The results, cover runs from 310041 to 310999, and can be modified to cover all runs, published to the online monitoring interface Monet in the trends section, and specifically organized into 52 pages of 4 plots each for the 2D occupancy trends and 6 pages of 12 subplots for the pseudo hit efficiencies. The purpose is to demonstrate the viability of this methodology for identifying performance variations across different ASICs, modules, and runs. The analysis provides insights into detector health and stability, laying the groundwork for publishing these detailed trend plots to the Data Quality Database (DQDB) for online monitoring.

1 Introduction

The Large Hadron Collider beauty (LHCb) experiment at CERN studies asymmetries between matter and antimatter. The VErtex LOcator (VELO) detector is crucial for the precise reconstruction of charged particle tracks and the accurate identification of primary and secondary interaction vertices. Operating within a high-radiation environment, maintaining the VELO's optimal performance is paramount. Pseudo hit efficiency quantifies how effectively charged particles traversing a sensor generate a detectable signal, providing insights into the detector's responsiveness. This is generally defined by the ratio:

$$\epsilon_{\text{pseudo hit}} = \frac{\text{Number of tracks passing selection criteria with a matched hit in the sensor}}{\text{Total number of tracks passing selection criteria intersecting the sensor's active area}}$$

Complementing this, sensor occupancy tracks the distribution and intensity of hits across the detector's pixel surfaces, offering crucial information on active areas and potential hotspots.

2 Monitoring Methodology

The selected histograms from LHCb savesets, specifically `VeloMonTrack` and `VeloMon`, were used to generate run by run trends. The analysis focuses on two primary categories of metrics:

- **Pseudo Hit Efficiency**: This metric is analyzed at a coarse and fine-grained level. At the coarse level the pseudo-efficiency is studied per ASIC position, averaged over all 52 modules of the detector, while at the detailed level the individual hit efficiency for every sensor across all 52 modules is plotted as a function of the LHC run number. This results in a comprehensive set of trend plots, which are then organized into a multi-page layout to facilitate the comparison and analysis of efficiency variations within specific ASIC and module groupings.
- **Occupancy Metrics**: The methodology includes a detailed study of 2D sensor occupancies, focusing on identifying and characterizing the most populated 2D regions (hotspots) on individual sensor cluster maps. These hotspots are specific two-dimensional areas within each VErtex LOcator sensor that consistently show the highest concentration of hits, programmatically defined by **x-bins (columns)** and **y-bins (rows)**.

  The specific hotspot definitions, derived from qualitative analysis of 2D occupancy histograms, are:

  - **Sensor 0:** x-bins [550, 750], y-bins [200, 250].
  - **Sensor 1:** x-bins [0, 250], y-bins [150, 250].
  - **Sensor 2:** x-bins [0, 200], y-bins [200, 250].
  - **Sensor 3:** x-bins [500, 750], y-bins [180, 250].

  These precise bin ranges enable the calculation and plotting of average occupancy trends within these most active zones, providing a focused measure of sensor performance, while avoiding contributions from the noisy regions of the sensors. Run 310070 was extensively used to identify these thresholds, with data from other runs randomly selected as controls to ensure robust region identification.

3 Results

Using the methodology described above, trend plots for the coarse level hit efficiency per ASIC are produced. While showing the different populations of runs, it is impossible to narrow it down to the specific sensor module and hence the need for a more detailed trend plotting.

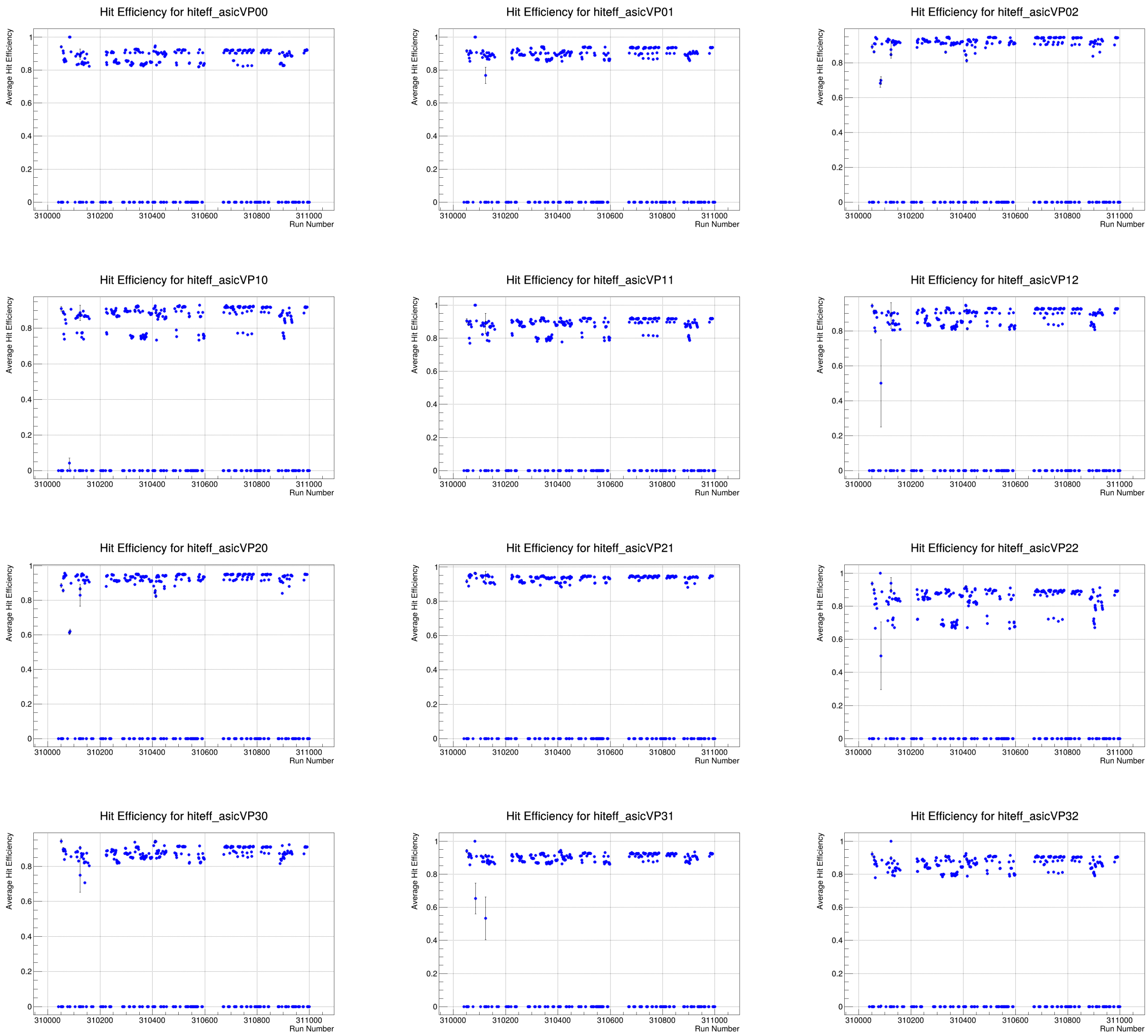

Figure 1: Twelve ASICS average hit efficiencies

Next a more detailed method is developed to be able to narrow down to hit efficiencies across the different ASICs and modules.(note: A total of 624 plots are needed but can be reduces by using multi page layout) For the occupancy metrics, the following results are obtained and published to Monet using the methodology defined earlier:

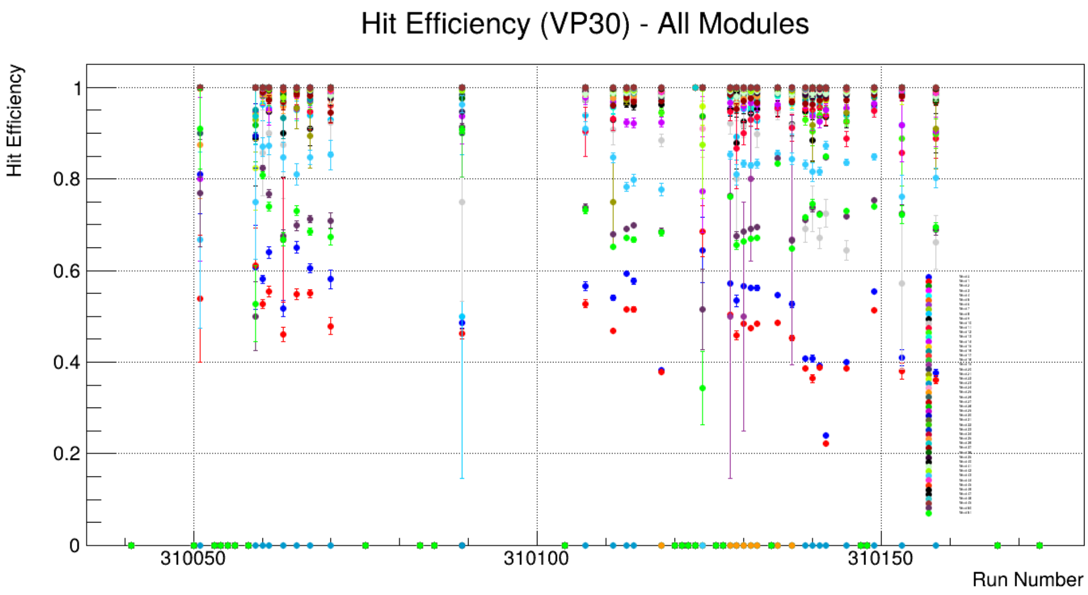

Figure 2: VP30 ASIC with all 52 modules

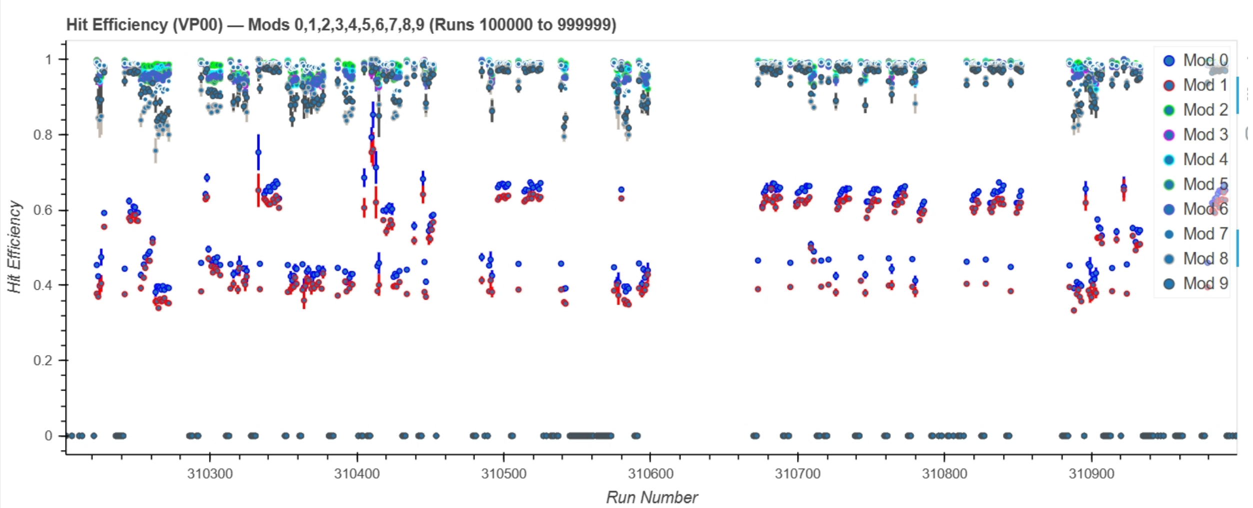

Figure 3: Reduced to 9 modules and published to Monet

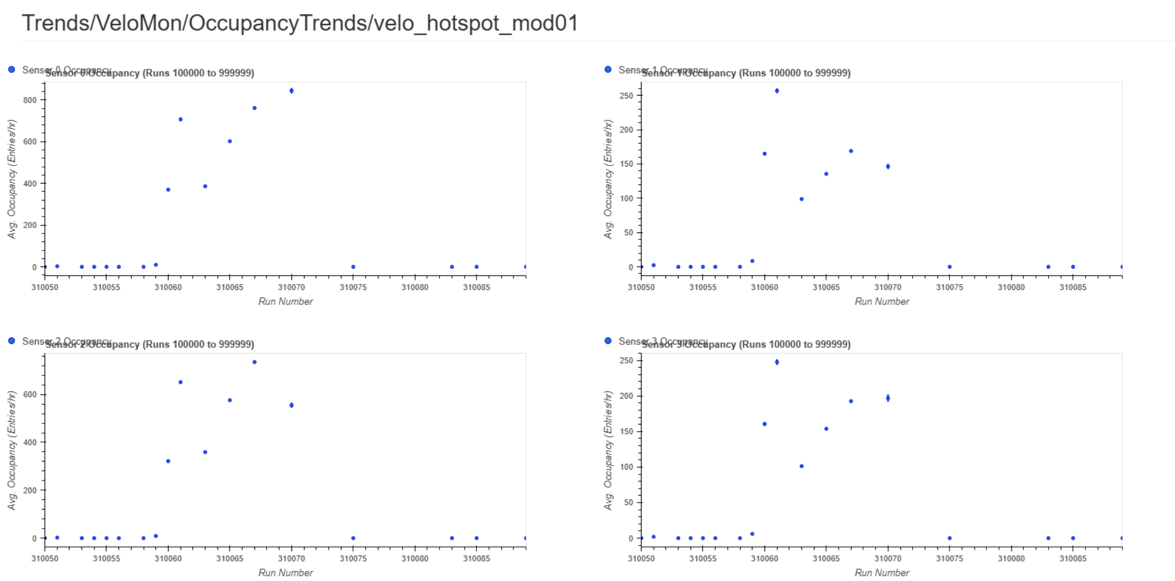

Figure 4: Occupancy Metrics for a few runs within the Range

4 Discussion

The trend-plots produced in this study provide a forward from coarse monitoring towards more detailed versions for the ASICs and modules. At the coarse level (Figure 1) shows higher and lower values for the per-ASIC position efficiency averaged over all modules for different runs. This necessitates a fine-grained plotting to localize performance variations down to the module and ASIC level (Figure 2 and Figure 3).

Interpreting the observed patterns leads to some key points:

- **Efficiency deviations:** Persistent lower efficiencies for particular ASICs are due to some biases introduced by the way the pseudo efficiencies are calculated. The trends make it possible to form targeted hypotheses about whether an observed effect is isolated (single ASIC/module/run) or correlated across neighbouring channels.
- **Occupancy behaviour:** The hotspot approach yields a compact metric that tracks the most active region of each sensor. Occupancy trends (Figure 4) show expected run-to-run variation: very short runs yield low average occupancies, while long runs produce stable, higher-average occupancies. Persistent, localized high-occupancy regions that do not follow beam conditions may indicate noisy electronics or reconstruction issues rather than physics-driven increases.

Limitations of the current implementation

While the current pipeline demonstrates feasibility and utility, several methodological limitations should be acknowledged:

- **Hotspot selection is currently manual/visual:** hotspot windows were defined from visual inspection of certain runs and then applied across runs. Fixed windows simplify the metric but may miss shifts in hotspot position in some scenarios. An automated, data-driven region definition (sliding-window integrals or clustering of the highest-fraction bins per sensor) would be more robust.
- **Limited run range and context variables:** the present results cover runs 310041–310999. Detector behaviour should be studied against additional contextual variables (instantaneous luminosity, integrated luminosity per run, fill number, run length, and DCS logs for temperatures / voltages) to pinpoint physics driven occupancy changes from hardware or operational causes.

References

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[2] LHCb collaboration, "LHCb VELO Upgrade Technical Design Report," CERN-LHCC-2013-021, 2013.

[3] M. Waterlaat et al., "Implementation and impact of data-driven VELO hit-efficiency corrections on early Run-3 simulation," LHCb-INT-2025-YYY, July 2025.